Jour. Agric. Res. China (中華農業研究) 33(1) : 001~011 (1984)

Hybrid Variety of *Indica* Rice and Its Yield Potential[1]

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Abstract : In a series of testcrosses, none of the varieties was found to restore the CMS of Reimei A (rufipogon), but many restored that of Chen-shan 97A (WA). Hybrid sterility seemed to limit the transfer of Rf-gene from an IR line to a *japonica* variety, Reimei. A row ratio of 4 : 1 or 6 : 1=A : B was found suitable for mechanical planting of A and B or and Rf lines in the hybrid seed production. Chen-shan 97 A, B gave a seedset percentage higher than 30 % or an yield of 1,288 kg/ha for seed production. The amount of hybrid seed produced for the first time in Taiwan was low, 562 kg/ha, which could be raised by increasing the row number of A line and by synchronizing the parental flowering times. Introduced hybrid variety Shan-you 6 gave a high yield of 9.5 t/ha in the first crop, but only about 6 t/ha in the second crop. The yield increase over the control vaiety as performed by the introduced and developed hybrid varieties seemed to be in the range of 20%-30% in the first crop and less than 10% in the second crop.

Introduction

Although cytoplasmic-genetic male sterility in rice was reported as early as 1966 (16) in Japan, followed by the intensive studies made by various researchers in many rice-growing countries (2,3,5,7,8,11,14,17,18,21,22,23), no commercial cultivation of hybrid rice has been known in the free world. Meanwhile, a rice acreage of 4.7 million ha. was reported to be planted to hybrid rice in China mainland in 1978 (15). Various hybrid varieties, including Shan-you 6 (Chen-shan 97A/IR26), inherited the male sterility cytoplasm from *Oryza sativa* L. f. *spontanea* on Hainan island or so-called WA type, and some IR strains were used as the fertility restorers (13). The writer started this line of work in 1974, mostly on *japonica* varieties (4,5,9) and later obtained several varieties of WA type male sterility through IRRI. The results on the development of a hybrid *indica* rice variety in Taiwan and its yield potential are reported here.

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1. Contribution No. 1139 from Taiwan Agricultural Research Institute, supported by the Council of Agricultural Planning and Development.

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Materials and Methods

(1) Testcross for fertility restorers : The first testcross experiment conducted in 1978 resulted in the indentification of 2 Rf-varieties of *indica* rice from about 70 entries tested. They partially restored the fertility of Reimei A (*rufipogon*). The progeny of Reimei A (*rufipogon*)/IR5032 cross was then used to propagate the segregating populations for selecting Rf-lines. In 1980, those lines selected from this IR5032 cross and the new *japonica* strains related to *Oryza rufipogon* were testcrossed (Table 1). Then, various IR strains or lines and other introductions were testcrossed in 1981 and 1982 (Table 1). We used the hot water method to promote the opening of florets and pollinated two panicles per cross with 20-30 florets per panicle. The seedset percentages and grain yields, when fertile, of the F_1's were investigated.

(2) Planting ratio of the CMS A and B lines : Using Chen-shan 97A (WA), B, and other MS varieties which we had developed, planting ratio experiments were conducted in 1981. In the first crop, we tested row-planting ratios of 1 : 1, 1 : 2, 1 : 4=A : B in two replications (Table 2), and then tested the row ratios of 1 : 1, 2 : 1, 3 : 1, 5 : 1=A : B in the second crop (Table 3). No isolation plot was set to avoid pollen contamination in these tests. The seedset percentage and grain yield of the A line were investigated.

(3) Production of hybrid seed : An isolated seed-production plot of hybrid variety rice was set up for the first time in Taiwan in the 1982 first crop. Chen-shan 97A (WA) and B, Toyonishiki A (*rufipogon*) and B, 16-3 A (Boro) and B participated in the MS seed producting. Hybrid rices HRTNGY 1 or Chen-shan 97A (WA)/Suween 293 and HRTNGY 2 or Chen-shan 97A (WA)/IR4563-52-1-3-6 were used for hybrid-seed production. A plot size of about 300 m^2 for Chen-shan 97A, B and its related cross combinations was employed with a row ratio of 5 : 2 for A and B or A and Rf lines. A nylon net at a height of about 2m was set up between different varieties or cross combinations to avoid pollen contamination as much as possible. We adjusted the seedling ages of the A and B lines at transplanting, or adjusted the transplanting dates of A and Rf lines to synchronize their heading stages. Flag leaves were cut back, followed by two sprays of 20 ppm G. A. before heading and then wind-blowing with a power blower during the heading stage to facilitate the dissemination of restorer pollen grains.

(4) Yield test of introduced hybrid varieties : Two hybrid varieties, namely Shan-you 6 and Zha-keng 1 were introduced by the Central Committee Secretariat of the Kuomintang, and the seeds were sent to our institute for tests, via the Council for Agricultural Planning and Development in late July, 1981. We used a large plot size of 13-20m^2 per entry in the 1981 second crop, and 9m^2 in the 1982 first crop for this test. Taichung Sen 3 and Taichung 67 served as the control. Each entry had two plots ; one was single-spaced and the other planted at 3-5 seedlings per hill. Their grain yields, yield components, agronomic characters, and rice quality were investigated. In the 1982 first crop, Shan-you 6 was tested simultaneously in an advanced *indica* rice yield trial.

(5) Yield test of the developed hybrid varieties.

The testcross F_1's that showed a normal seedset were simultaneously used to estimate

their yield potentials for a quick screening, although the number of plants per cross ranged mostly between 20-60. Based on these data, two combinations were selected, i. e. HRTNGY 1 (Chen-shan 97A/Suweon 293) and HRTNGY 2 (Chen-shan 97A/IR4563-52-1-3-6) for seed production in the 1982 first crop season. Then, the two hybrid varieties participated in an observational test. They were single-spaced and also planted at 3-5 seedlings per hill in the 1982 second crop. For a more accurate test of hybrid variety grain yields, we selected 20 cross combinations based on the performances of the F_1's and produced hybrid seeds by hand mass-pollination in the 1982 first crop, then, yield-test was conducted in the following season in a randomized complete block design with four replications. Grain yield and other related characters were investigated according to the method used in the ordinary advanced yield trial.

Results and Discussion

(1) **Testcross for fertility restorer :**

None of the lines selected from the cross of Reimei A (*rufipogon*)/IR5032 restored the fertility of Reimei A (*rufipogon*), although some lines did to a slight degree (Table 1). Nor did the breeding lines related to *Oryza rufipogon* restore the fertility (Table 1). We backcrossed the F_1 of Reimei A (*rufipogon*)/IR5032 to Reimei using Reimei as the pollen parent. The plants with Rf-gene did not recover in the BC_1F_1. It seems that hybrid sterility limited the transfer of Rf-gene from IR5032 (*indica*) to Reimei (*japonica*). Some of the testcrossed lines related to IR5032, on the other hand, restored completely the fertility of I-geo-gen A (Boro), whose sterility had been relatively unstable, and also restored the fertility of Chen-shan 97A (WA)(Table 1). In the 1981 and 1982 testcrosses, many Rf-varieties were identified as being able to restore the fertility of Chen-shan 97A (WA). Most of them were IR strains that were related to a wild species of *Oryza*. Generally, the CMS's of Chinsurah Boro II and Pai-ko were relatively unstable under Taiwan conditions[5], while those of *rufipogon* and *spontanea* or WA type

Table 1. Seedset percentages of the testcross F_1's for fertility restorers.

Testcross Parents		TC F_1 seedset percentage										
♀	♂	5	15	25	35	45	55	65	75	85	95	Total
Reimei A (*rufipogon*)	*O. rufipogon* related strains	17										17
	IR5032 related lines	22	11	2								35
	others	5										5
I-geo-gen A (Boro)	IR 5032 related lines			2	2	5	3	6	12	8		38
Chen-shan* 97 (WA)	IR5032 related lines	4	8	8	8	8	10	3	11	2	1	63
	1981-II test	11	20	12	12	12	9	22	27	29	7	161
	1982-I test	38	31	15	15	18	11	27	39	33	15	242

*Also spelling Zhen-shan.

Table 2. Seedset percentage of *A* line of the CMS variety at three planting ratios of *B* to *A* lines (1981 1st crop).

Planting ratio	Chen-shan 98A (WA)		Reimei A (rufipogon)		16-3A (Boro)	
A : B	Bagged	Unbagged	Bagged	Unbagged	Bagged	Unbagged
1 : 1	0.49	22.0	0.15	7.0	2.3	8.0
1 : 2	0.51	24.4	0.57	4.7	1.5	7.8
1 : 4	1.80	25.4	0.00	5.3	1.6	7.9

were stable.

(2) **Planting ratio of the CMS A and B lines :**

An increase in the row number of B line did not improve the seedset percentage of the A line in three CMS varieties tested. We can say that an increased supply of pollen grains did not promote the chance of cross-fertilization. Unbagged Chen-shan 97A (WA) showed a higher outcrossing rate of 22%-26%, while two other *japonicas* had a rate of less than 8% (Table 2). Ten to 20 percent of the seeds harvested from these A lines produced plants which exhibited off-type characteristics, indicating that they were the results of pollen contamination. Chen-shan 97 had its stigma protruding outside, even after the floret had closed, and also a logner period of floret opening. One half of the protruding stigma after the floret closed was found to be functional for fertilization for four hours in the morning[9]. Apparently, the flowering habit and flower structure of Chen-shan 97 contribute to this higher rate of outcrossing.

This conclusion can be supported by another CMS variety, Reimei A (*rufipogon*) which has a very low outcrossing rate (Table 2), since its stigmas are very small and never protrude outside the floret or glumes. The period of its floret opening is very short and the frequency of floret opening is also low.

On the other hand, an increase in the row number of A line in a range of 1—5 with one row of B line did not reduce the seed production of CMS varieties (Table 3). Accordingly, yields of hybrid seed increased proportionately as the row number of A line incceased, within the range of row ratios A : B=1 : 1 to =8 : 2[13]. A row ratio of 6 : 1= A : B is widely used for seed production in China mainland[13]. We used a ratio of 5 : 2 or 4 : 1=A : B in the production of hybrid seed for experimental purposes. For commercial production of hybrid seed, it is recommended to use a ratio of 4 : 1 or 6 : 1=A : B in order to accomodate the rice transplantor.

A high amount of MS seed produced by 16-3A (Boro) and IGGA (Boro) (Table 3) was caused by self-fertilization, since their bagged panicles also showed a higher seedset percentage. As mentioned before, MS lines with Chinsurah Boro II cytoplasm were unstable in male sterility. Therefore, we concentrated thereafter on Chen-shan 97A (WA) for hybrid seed production.

Table 3. Amount of MS-line seed production (g/10m^2) at different planting ratios of *B* to *A* lines (1981 2nd crop).

Planting ratio A : B	Chen-shan 97A (WA)	16-3A (Boro)	34-60A (Boro)	IGG A (Boro)
1 : 1	94	100	29	1,128
2 : 1	135	150	29	857
3 : 1	67	203	20	943
5 : 1	91	115	25	1,355

Table 4. Seedset percentage and seed production of CMS-lines and hybrid variety with a row ratio of A : B=5 : 2 (1982 1st crop).

Item	2.4-D treatment	Chen-shan 97A (WA)(♀)	Chen-shan 97B(♂)	Chen-shan 97A (WA)(♀)	Suweon 293Rf(♂)
Seedset percentage	−	33.6	85.8	18.0	76.0
	+	7.2	75.7	—	—
Seed production(kg/ha)	−	1,288	—	562	—
	+	587	—	—	—

(3) Hybrid seed production

Two steps are needed in hybrid seed production ; one is the MS seed production and the other, hybrid seed. Of three CMS varieties that participated in the seed production, only Chen-shan 97A, B (WA) gave a seedset percentage higher than 30 % and a production rate of 1,288 kg/ha seed (Table 4). Two other *japonica* varieties, Toyonishiki A (*rufipogon*) and 16-3A (Boro), showed a seedset percentage lower than 5 %. Unless some measures are taken to increase their outcrossing rates, the two varieties are practically useless for hybrid variety development. In an attempt to develope such a measure, we sprayed the CMS A lines with 1/800 2,4-D before blooming. The chemical did maintain the opening of florests for more than 3 days. However, these opened florets turned out to be pseudograin-like and greatly reduced the seedset percentage and the amount of seed produced (Table 4).

The amount of hybrid seed produced for the first time in Taiwan was very low, 562 kg/ha in HRTNGY 1 or Chen-shan 97A (WA)/Suweon 293 (Table 4) and even lower than this in HRTNGY 2. Since the MS and Rf varieties all belong to tropical *indica*, they are sensitive to low temperatures when cold fronts invade. Any variety hit by a cold front at the flower initiation stage will spend a considerable time lagging in panicle heading, which may disturb the synchronization of the flowering times of A and Rf lines.

Therefore, the late planted first crop rice is probably more suitable for hybrid seed production in such *indica* rice.

Since a row ratio of 5 : 2 = A : B was used in the above mentioned seed production, we could increase the unit-area yields of MS seed and hybrid seed production by increasing the row number of A lines. Synchronization of the A and B line heading times of a MS variety needs further improvement. The heading time of A line generally is late than B line by about three days, and its time of floret opening is later than that of the B line by about 3 hours every day. By solving these timing gaps in the A and B or A

Table 5. Grain yield and lts related traits of hybrid rice Shan-you 6 and the controls.

Variety \ Traits	Year season	Grain yield: Single plant per hill t/ha	Single plant per hill %	3-5 seedings per hill t/ha	3-5 seedings per hill %	Grain No./ panicle	Seedset (%)	1,000 grains wgt. (g)	Grain straw ratio	Volume weight (g/L)
Shan-you 6	'81Ⅱ	5.4	102	5.9	101	97	80	27.2	1.12	—
	'82Ⅰ	8.5	125	9.5	127	101	82	27.3	1.17	549
Shan-you 6 progeny	'82Ⅰ	5.7	84	6.3	84	100	63	25.9	0.81	543
Taichung Sen 3 (CK_1)	'81Ⅱ	5.3	100	5.8	100	89	77	26.1	0.98	—
	'82Ⅰ	6.8	100	7.5	100	104	68	26.3	0.96	497
Tainung 67 (CK_2)	'81Ⅱ	5.4	100	5.5	—	89	88	26.6	0.96	—
	'82Ⅰ	7.3	100	7.8	—	89	80	25.2	1.13	543

Table 6. Agronomic traits of Shan-you 6 and the controls.

Ⅱ crops : seeded on 31/Ⅶ, 1981 transplanted on 11/Ⅷ 1981
Ⅰ crops : seeded on 2/Ⅱ, 1982, transplanted on 25/Ⅱ, 1982

Variety \ Trait	Year Season	Maturing stage: Pl. height (cm)	Panicle No.: Single pl. per hill	Panicle No.: 3-5 plants per hill	Growth duration (day): Transpl. to heading	Growth duration (day): Transpl. to maturing	Lodging	Pests	Shattering
Shan-you 6	81Ⅱ	91	11	14	57	93	no	none	easy
	82Ⅰ	100	14	22	78	100	no	none	easy
Shan-you 6 progeny	82Ⅰ	93	14	21	80	114	no	none	easy
Taichung Sen 3 (CK_1)	81Ⅱ	88	11	15	68	104	no	none	easy
	82Ⅰ	93	16	24	98	132	no	none	easy
Tainung 67 (CK_2)	81Ⅱ	94	10	13	65	105	no	none	Intermediate
	82Ⅰ	114	16	23	88	122	no	none	Intermediate

and Rf line flowering habits, we may be able to boost the seedset percentage of A lines to 40% or more, which seems to be economical for commercial production of hybrid rice.

(4) **Yield of the introduced hybrid**

Only two varieties were introduced, i. e. Shan-you 6 and Zha-keng 1. Zha-keng 1 belonging to *japonica* was very early maturing and low in grain yield. The agronomical performance of Shan-you 6 is shown in Table 5 and 6. This hybrid variety, commonly grown in China mainland, produced a yield of rough rice 9.5 t/ha in the first crop, and about 6 t/ha in the second crop (Table 5). Its yield increase over Taichung Sen 3 was 27% in the first and 1% in the secound crops (Table 5). An increase in the number of seedings per hill from 1 to 3-5 resulted in a slight yield increase. In the advanced yield trial of the 1982 first crop, Shan-you 6 yielded as high as 8.5 t/ha, the highest yield of all entries tested. Its yield surpassed that of Taichung Sen 10 by 10.1 percent. The progeny of Shen-you 6 produced a lower yield, due to the reduction of hybrid vigor and seedset percentage (Table 5). Shan-you 6 was very susceptible to low temperatures, which was obvious by the severe discolaration of leaves after cold front invasions, particularly in the late second crop season.

Table 7. Rice quality of Shan-you 6 and the controls (Taichung DAIS).

Variety \ Quality traits	Milled %	Head rice %	Grain appearence: Length	Shape	Trans-parency	White core	White belly
Shan-you 6	67.7	60.2	MS-M	I	4	0	4
Taichung Sen 3 (CK_1)	72.2	61.4	ML	S	2	1	1
Tainug 67 (CK_2)	72.1	67.0	S	B	3	1	2

Variety \ Quality traits	Alkali test: Spreading	Gelatinization temp.	Amylose (%)	Protein (%)	Gel consistency
Shan-you 6	5.8	H	27.7	7.5	H
Taichung Sen 3 (CK_1)	6	L	19.6	8.6	L
Tainung67 (CK_2)	6	L	18.8	7.6	L

Note : 1. length 5.51mm=S, 5.51–6.1mm=MS, 6.1–6.61mm=M, 6.61–7.06=ML.
2. Shape : B=broad, I=intermediate, S=slender.
3. Transparency, White core, White belly, all have 0-5 classes.

One thing worth of note is that Shan-you 6 had a higher grain straw ratio than the control variety in both crops, primarily due to its heavy grain weight (Table 5). The photosynthetic efficiency of hybrid rice was higher than that of the parents during

Table 8. Examples of yield data of the testcross F_1's (1982-I)

Crosss combination		No. of plants	Grain yield	
♀	♂		kg/ha	%
Chen-shan 97 (WA)	5040	50	8,333	117
Chen-shan 97 (WA)	IR2071-588-4-4	60	8,481	120
Chen-shan 97 (WA)	Bahagia	43	8,409	118
Chen-shan 97 (WA)	LI-109-1-1	33	9,260	130
Chen-shan 97 (WA)	CAS 209	35	8,698	123
Chen-shan 97 (WA)	IR2058-85-3-3	35	8,222	116
Taichung Sen 10 (CK)		100	7,100	100

most of the growth period, particularly in the tillering stage(13). On the other hand, the respiration intensity of the hybrid rice was lower than that of the parents(13). Shan-you 6 seemed to have a larger green leaf area at every growth stage in the first but not in the second crops and also a bigger grain size, indicating that its sizes of sink and source were much larger than the control varieties in the first crop.

The rice quality of Shan-you 6, as determined by the Rice Quality Laboratory, Taichung District Agricultural Experiment Station, is shown in Table 7. Its milling quality, including the percentage of head rice was relatively poor, with high score readings in white belly and transparency. Since its amylose content reached as high as 27.7 % with a hard gel consistency, the market value of this rice will be much lower in Taiwan.

(5) **Yield of the developed hybrid**

The testcross F_1's not only gave us evidence for identifying fertility restorers, but also provided the preliminary yield data for a quick screening. Table 8 shows the yields of high yielding entries of testcross F_1's grown in the 1982 first crop. The range of their yield increases over Taichung Sen 10 was about 20%-30%. Based on the results obtained from the introduced and developed hybrid varieties, the yield increases of hybrid rice over the control variety seems to be about 20%-30% in the first crop season.

The yield increase of hybrid rice over the control variety in the second crop season was much lower. HRTNGY 1 exhibited an yield increase of only 2%-6% and HRTNGY 2, −7% ~0% over Taichung Sen 10 in the second crop season (Table 9). In the replicated yield trial, many entries gave an yield of more than 8 t/ha. Their yield increases over Tainung 67 reached to more than 30%, which would probably drop to less than 10% when compared with Taichung Sen 10.

The high yield potential of semidwarf *indica* rice has been widely acknowledged after the development of IR8, for which Taichung Native 1 serves as the conceptual variety. This group of cultivar generally exhibit a high yield potential under favorable environments. Therefore, the regression coefficients between environment mean and variety

Table 9. Observational trial of 2 hybrid varieties of rice (1982 2nd crop).

Entry	Parents	No. of seedings per hill	Grain yield kg/ha (%)	Plant hgt. (cm)	Panicle No.	Days from transpl. to harvesting
HRTNGY 1	Chen-shan 97A /Suweon 293	1	9,426(106)	106	9.4	96
		3—5	9,100(102)	107	11.0	93
HRTNGY 2	Chen-shan 97A /IR4563-52-1-3-6	1	8,296(93)	105	8.3	92
		3—5	8,900(100)	111	12.0	96
Taichung 10 (CK_1)		3—5	8,889(100)	107	8.9	100
Tainung 67 (CK_2)		3—5	6,667	107	6.7	100

Table 10. Replicated yield trial of hybrid strains of rice (1982 2nd crop).

Entry No.	Parents	Grain yield (kg/ha)	Days from tranpl. to flower.	Plant height (cm)	Panicle No.	Seedset %	No. grain/ panicle	1000 grain wgt. (g)
1	Chen-shan 97A/IR28	7,696	51	97	16	88	94	25.4
2	Chen-shan 97A/IR30	8,689	62	97	14	78	130	24.7
3	Chen-shan 97A/IR50	8,402	52	97	17	81	106	23.5
4	Chen-shan 97A/IR9129 -209-2-2-2-1	8,278	61	100	17	87	116	24.7
5	Chen-shan 97A/IR4563	7,744	63	98	14	82	110	28.0
6	Chen-shan 97A/IR13240	7,942	50	88	16	82	106	25.0
7	Chen-shan 97A/Suweon 293	8,204	64	97	15	71	124	25.5
8	Chen-shan 97A/9719	7,487	57	100	16	86	124	24.3
9	Chen-shan 97A/9733	7,364	59	101	12	76	133	30.2
10	Tainung 67	6,529	65	107	17	86	100	24.2

mean yields are generally higher; or their yield potentials are high, but they have a high regression coefficient or low general stability[10]. In the hybrid variety produced from these semidwarf *indicas*, there are two possibilities concerning environmental adaptation: the first is that the heterozygosity and uniformity of the hybrid variety bring about an improvement in its stability, so that it adapts better to a wider range of different environments; and the second is that the hybrid vigor of yield potential manifests itself even higher under favorable environments, but not under unfavorable environments, therefore, its general stability is low.

From the above results, it seems that the second possibility is more likely. We recommended two hybrid strains, namely HRTNGY 1 and 2 to participate in the *indica* regional yield trial in 1983. More accurate conclusions dealing with the environmental adaptation of hybrid rice will be drawn after the completion of this trial.

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秈稻雜種品種及其產量潛力[1]

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摘　要

本文報告秈稻雜種品種之育成及其產量潛力。多次檢驗交配結果顯示，現有育成系統、品系或品種均未能恢復 Reimei A (*rufipogon*) 之雄不稔性，但有多數品種（系）恢復 Chen-shan 97A (WA) 之不稔性。秈粳型間雜種不稔性似限制稔性恢復基因從一個 IR 品系轉移至粳型的 Reimei。生產雜種種子所需 A、B 系統或 A、Rf 系統之種植行數比，以4：1或6：1=A：B或 A：Rf較適合於機械插秧。雄不稔品種 Chen-shan 97A, B 有 30% 以上之結實率，種子生產量達1,288公斤／公頃。目前的雜種品種種子生產量低，僅有 562 公斤／公頃，有可能以增加 A 系統之行數及同步化兩親的開花期來將之大幅提高。引進雜種品種汕優 6 號在第一期作產量達 9.5 公噸／公頃，第二期作 6 公噸／公頃。引進及育成雜種品種的一般產量潛力似比對照品種高約20%～30%（第一期作），及10%以下（第二期作）。

1. 臺灣省農業試驗所　研究報告第 1139 號。本試驗承行政院農業發展委員會之補助。
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